Lesson 4

Electrostatic Precipitators

Lesson Goal and Objectives

Goal

To familiarize you with the particulate emission removal device used by many industries — the electrostatic precipitator — its operating principles, and the different designs in use.

Objectives

At the end of this lesson, you should be able to:

1. recall how particles are collected in an electrostatic precipitator (ESP).
2. list four major components of an ESP.
3. recall the location of a hot-side precipitator.
4. recognize three types of rappers and recall their operation principles.
5. define resistivity and recall how it can be altered to improve ESP performance.
6. define aspect ratio and specific collection area.
7. list three industrial applications for ESPs.

Introduction

Electrostatic precipitators (ESPs) have been used to reduce particulate emissions in many industrial applications for over fifty years. ESPs have been designed to collect particles with diameters of from 0.1 μm to 10.0 μm; collection efficiency is considered high, sometimes exceeding 99%. The ability of ESPs to handle large exhaust gas volumes at temperatures between 175 and 700°C (350 to 1300°F) makes them very attractive to many industries. This ability is particularly desirable for cement kiln emission reduction and for control of emissions from basic oxygen steel furnaces in the steel industry where flue gas enters the precipitators at temperatures greater than 350°C (660°F). ESPs are commonly used for particulate emission reduction for black liquor operations in the pulp and paper industry, for blast furnaces and sintering operations in the steel industry, and for fly ash control from industrial and utility boilers.

ESP Description

An electrostatic precipitator, depicted in Figure 4-1, contains six essential components. Each of these components will be discussed in detail in this lesson:

- discharge electrode
- collection electrode
- electrical system
- rapper
- hopper
- shell

The *discharge electrode* is usually a small-diameter metal wire. This electrode is used to ionize the gas (that charges the particles) and to create a strong electric field. The *collection electrode* is either a tube or a flat plate with an opposite charge relative to that of the discharge electrode. The collection electrode collects charged particles. The *electrical system* consists of high voltage components used to control the strength of the electric field between the discharge and collection electrodes.

The *rapper* imparts a vibration or shock to the electrodes, removing the collected dust. Rappers remove dust that has accumulated on both collection electrodes and discharge electrodes. Occasionally, water sprays are used to remove dust from collection electrodes. These precipitators are called water-walled ESPs. *Hoppers* are located at the bottom of the precipitator. Hoppers are used to collect and temporarily store the dust removed during the rapping process. The *shell* structure encloses the electrodes and supports the entire ESP.

ESPs that use plates as collection electrodes are called plate precipitators. ESPs that use tubes for collection electrodes are called tubular precipitators.

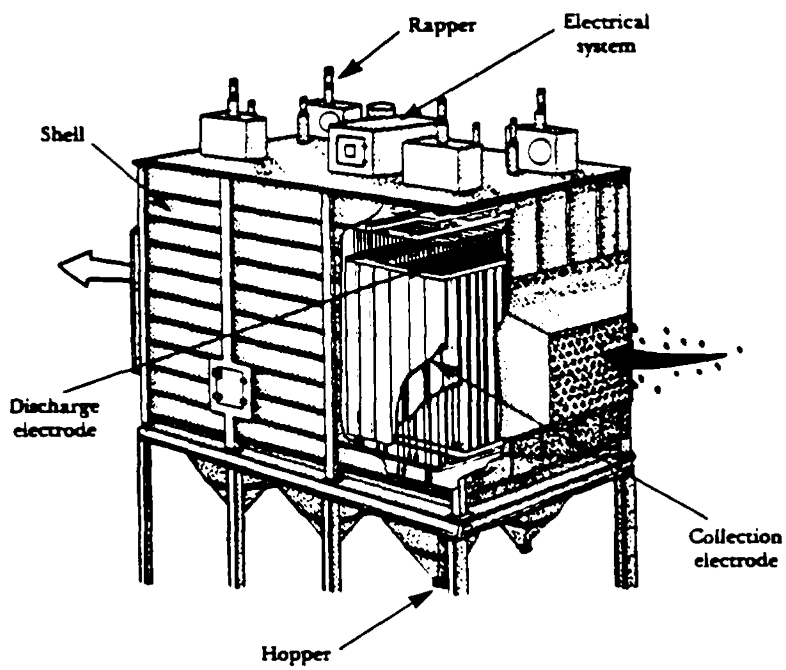

Figure 4-1. Typical electrostatic precipitator.

Plate ESPs

Plate electrostatic precipitators are used more often than tubular precipitators. A high voltage creates an intense electric field which charges the particles as the flue gas passes through the precipitator. Dirty gas flows into a chamber consisting of a series of discharge electrodes—wires equally spaced along the center line of adjacent plates (Figure 4-2). Discharge electrodes are approximately 0.13 to 0.38 cm (0.05 to 0.15 in.) in diameter. Collection plates are usually between 6 and 12 m (20 and 40 ft) high. The plates are usually spaced from 20 to 30 cm (8 to 12 in.) apart.

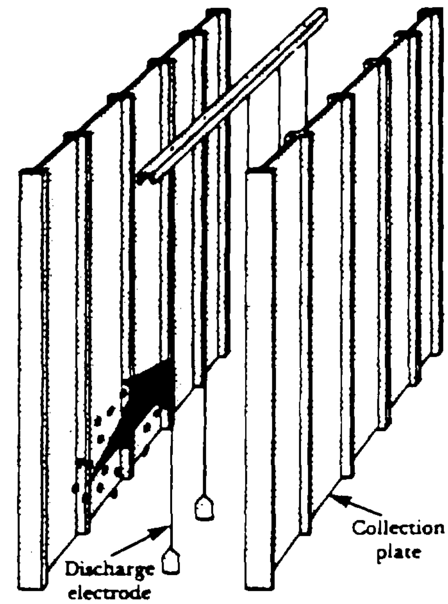

Figure 4-2. Gas flow through a plate precipitator.

Tubular ESPs

Tubular precipitators consist of cylindrical collection electrodes (tubes) with discharge electrodes (wires) located in the center of the cylinder (Figure 4-3). Dirty gas flows into the tubes where particles are charged. Charged particles are collected on the inside walls of the tubes. Collected dust or liquid is removed by washing the tubes with water sprays located directly above the tubes. Tubular precipitators are generally used for collecting mists or fogs. Tube diameters typically vary from 0.15 to 0.31 m (0.5 to 1 ft), with length usually varying from 1.85 to 4.0 m (6 to 15 ft).

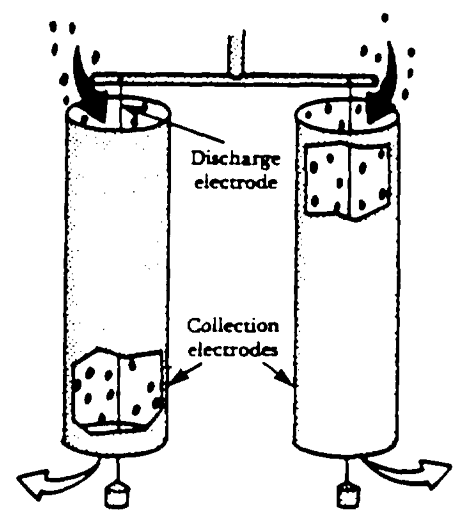

Figure 4-3. Gas flow through a tubular precipitator.

Hot-side ESPs

Hot-side ESPs are electrostatic precipitators placed in locations where the flue gas temperature is relatively high. They can be either tubular or plate. Hot-side precipitators are used in high temperature applications such as in the collection of utility and industrial boiler fly ash. A hot-side precipitator is located before the combustion air preheater in a boiler, whereas a cold-side precipitator is located after the air preheater. The flue gas temperature here for hot-side precipitators is in the range of 320 to 420 °C (608 to 790 °F). The use of hot-side precipitators also helps reduce corrosion and hopper plugging. However, hot-side precipitators have some disadvantages. Since the temperature of the flue gas is higher, the volume of gas to be treated in the ESP is larger. Consequently, the overall size of the precipitator will be larger. Another major disadvantage includes structural and mechanical problems that occur in the precipitator shell and support structure. Structural distortions stem mainly from differences in thermal expansion between the shell and the support structure.

Particle Collection

Charging the Particles in the Precipitator

Since the majority of precipitators have plates as collection electrodes, plate ESPs will be used for this discussion. Particles suspended in flue gas are charged as they pass through electrostatic precipitators. A high-voltage, pulsating, direct current is applied to an electrode system consisting of a small diameter discharge electrode and a collection electrode. The discharge electrode is usually negatively charged. The collecting plate is usually grounded. The applied voltage is increased until it produces a *corona discharge* which can be seen as a luminous blue glow around the discharge electrode. The corona causes gas molecules to ionize. The negative gas ions that are produced migrate toward the grounded collection electrode. The negative gas ions bombard the particles suspended in the flue gas stream, imparting a negative charge to them. Negatively charged particles then migrate to the collection electrode and are collected (Figure 4-4).

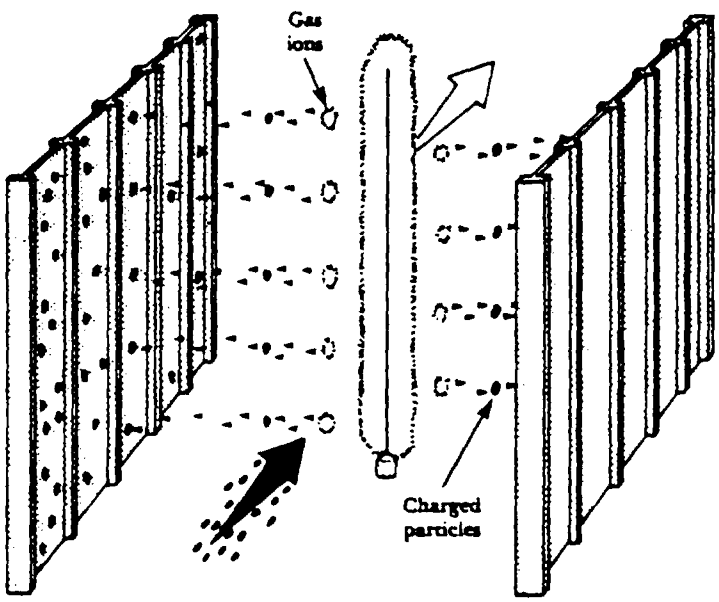

Figure 4-4. Particle charging.

Discharging the Particles at the Collection Electrode

When a charged particle reaches the grounded collection electrode, the charge on the particle is only partially discharged. The charge is slowly leaked to the grounded collection plate. A portion of the charge is retained and contributes to the intermolecular cohesive and adhesive forces that hold the particles onto the plates. Particles are held to the plates by adhesive forces. Newly arrived particles are held to the collected particles by cohesive forces. The dust layer is allowed to build up on the plate to a thickness of 0.08 to 1.27 cm (0.03 to 0.5 in.), and then the rapping cycle is initiated. Rapping cycles are initiated on a set-timed cycle.

Rapping the Particles into the Hopper

Periodically rapping the precipitator plates is necessary to maintain the continuous flue gas cleaning process. The plates are rapped while the ESP is on-line; the gas flow continues through the precipitator and the applied voltage remains constant. In wet-walled precipitators, tubes are cleaned by water sprays. In most other precipitators, deposited dry particles are dislodged by sending mechanical impulses or vibrations to the plates. Plates are rapped when the accumulated dust layer is relatively thick (0.08 to 1.27 cm). This allows the dust layer to fall off the plates as large aggregate sheets and helps eliminate dust reentrainment. Most precipitators have adjustable rappers so that rapper intensity and frequency can be changed according to dust concentration in the flue gas.

Dislodged dust falls from the plates into the hopper. The hopper is a single collection bin with sides sloping approximately 60° to allow dust to flow freely from the top of the hopper to the discharge opening. Dust should be removed as soon as possible to avoid (dust) packing. Packed dust is very difficult to remove. Most hoppers are emptied by some type of rotary discharge device, screw conveyor, or pneumatic conveyor. A typical hopper with a screw conveyor is shown in Figure 4-5.

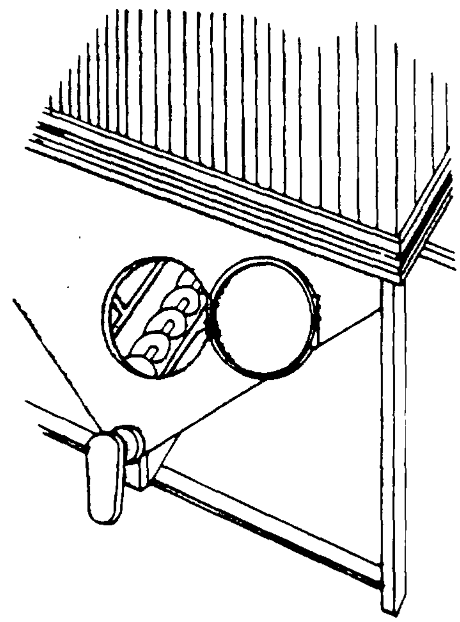

Figure 4-5. Hopper and screw conveyor.

Review Exercise

1. In an electrostatic precipitator, the ________ electrode is normally a small-diameter metal wire.	
2. The charged particles migrate to and are collected on the ________.	1. discharge
3. ________ are used to remove dust from both the collection electrodes and the discharge electrodes.	2. collection electrode
	3. Rappers

4. In a single stage, high voltage ESP, the applied voltage is increased until it produces a(an) a. extremely high alternating current for particle charging. b. corona discharge which can be seen as a blue glow around the discharge electrode. c. corona spark that occurs at the collection electrode.	
5. True or False? Particles are usually charged by negative gas ions that are migrating toward the collection electrode.	4. b. corona discharge which can be seen as a blue glow around the discharge electrode.
6. As dust particles reach the grounded collection electrode, their charge is a. immediately transferred to the collection plate. b. slowly leaked to the grounded collection electrode. c. cancelled out by the strong electric field.	5. True
7. Particles are held onto the collection plates by a. a strong electric field force. b. a high pulsating direct current. c. intermolecular cohesive and adhesive forces. d. electric sponsors.	6. b. slowly leaked to the grounded collection electrode.
8. True or False? During the rapping process, the voltage is turned down to about 50% of the normal operating voltage to allow the rapped particles to fall freely into the hopper.	7. c. intermolecular cohesive and adhesive forces.
	8. False

Precipitator Components

Discharge Electrodes

The discharge electrodes in many U.S. precipitator designs are thin round wires varying from 0.13 to 0.38 cm (0.05 to 0.15 in.) in diameter. Most common designs use wires approximately 0.25 cm (0.1 in.) in diameter. The discharge electrodes consist of vertically hung wires supported at the top and held taut and plumb by a weight at the bottom. The wires are usually made from high carbon steel, but have also been constructed of stainless steel, copper, titanium alloy, Inconel®, and aluminum. The weights are made of cast iron and are generally 11.4 kg (25 lbs) or more.

Discharge wires are usually supported to help eliminate breakage from mechanical fatigue. The wires move under the influence of aerodynamic and electrical forces and are subject to mechanical stress. The weights at the bottom of the wire are attached to guide frames to help maintain wire alignment. Attaching the weights will prevent them from falling into the hopper in the event that the wire breaks (Figure 4-6). The bottom and top of each wire are usually covered with a shroud of steel tubing. The shrouds help minimize sparking and consequent metal errosion by sparks at these points on the wire.

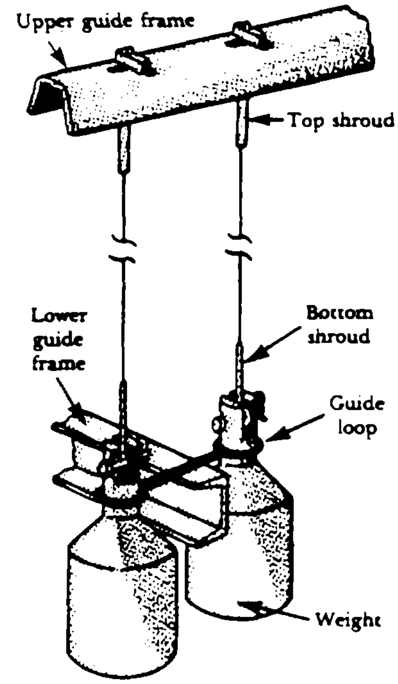

Figure 4-6. Guide frames and shrouds for discharge wires.

The size and shape of the electrodes are governed by the mechanical requirements of the system. Most U.S. designs have traditionally used thin, round wires for corona generation. Some designers have also used twisted wire, square wire, barbed wire, or other configurations. Some of these are illustrated in Figure 4-7.

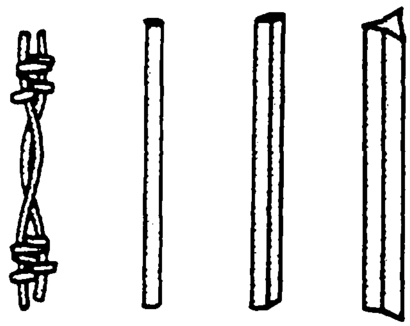

Figure 4-7. Typical discharge electrodes.

European precipitator manufacturers favor the use of rigid support frames for discharge electrodes. The frames may consist of coiled spring wires, serrated strips, or needle points mounted on a supporting strip. An example is shown in Figure 4-8. The purpose of the rigid frame is to eliminate the possible swinging of the discharge wires. These designs have been used as successfully as the U.S. wire designs. Many U.S. vendors are now using rigid frame discharge electrodes.

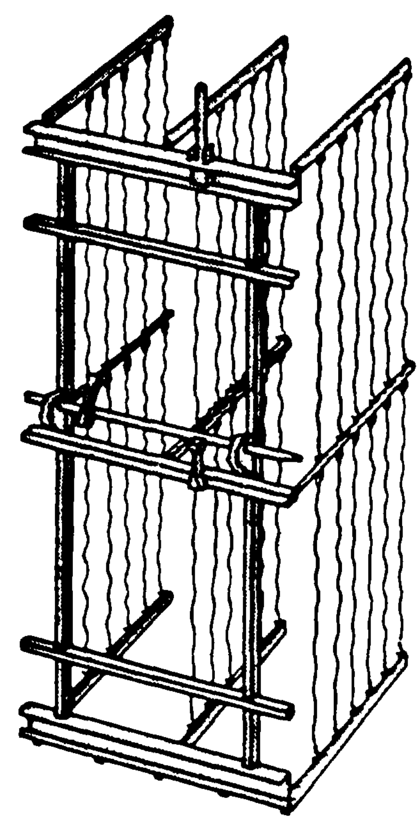

Figure 4-8. Rigid frame discharge electrode design.

Collection Electrodes

Most U.S. precipitators use plate collection electrodes because they treat large gas volumes and usually have high collection efficiency. The plates are generally made of carbon steel. However, plates are occasionally made of stainless steel or an alloy steel for special flue gas stream conditions. The plates range from 0.05 to 0.2 cm (0.02 to 0.08 in.) in thickness. Plates are spaced from 20 to 30 cm apart (8 to 12 in.). Normal spacing for high efficiency ESPs is 20 to 23 cm (8 to 9 in.). Plates are usually between 6 and 12 m (20 to 40 ft) high.

Collection plates are constructed in a number of shapes as shown in Figure 4-9. These plates are solid-sheets that are sometimes reinforced with structural stiffeners to increase plate strength. In some cases, the stiffeners act as baffles to help reduce particle reentrainment losses.

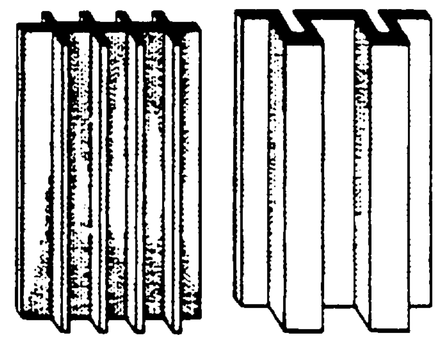

Figure 4-9. Typical collection plates.

Shell

The shell structure encloses the electrodes and supports the precipitator components in a rigid frame to maintain proper electrode alignment and configuration (Figure 4-10). The support structure is especially critical for hot-side precipitators because precipitator components can expand and contract when the temperature differences between the ESP (400 °C) and the ambient atmosphere (20 °C) are large. Excessive temperature stresses can literally tear the shell and hopper joints and welds apart.

Collecting plates and discharge electrodes are normally supported from the top so that the elements hang vertically because of the force of gravity. This allows the elements to expand or contract with temperature changes without binding or distorting.

Shells, hoppers, and connecting flues should be covered with insulation to conserve heat, and to prevent corrosion due to water vapor and acid condensation on internal precipitator components. Insulation will also help minimize temperature differential stresses, especially on hot-side precipitators. Ash hoppers should be insulated and heated. Cold fly ash has a tendency to cake; therefore, it is extremely difficult to remove.

The precipitator should also be designed to provide easy access to strategic points of the collector for internal inspection of electrode alignment, for maintenance, and for cleaning electrodes, hoppers, and connecting flues during outages.

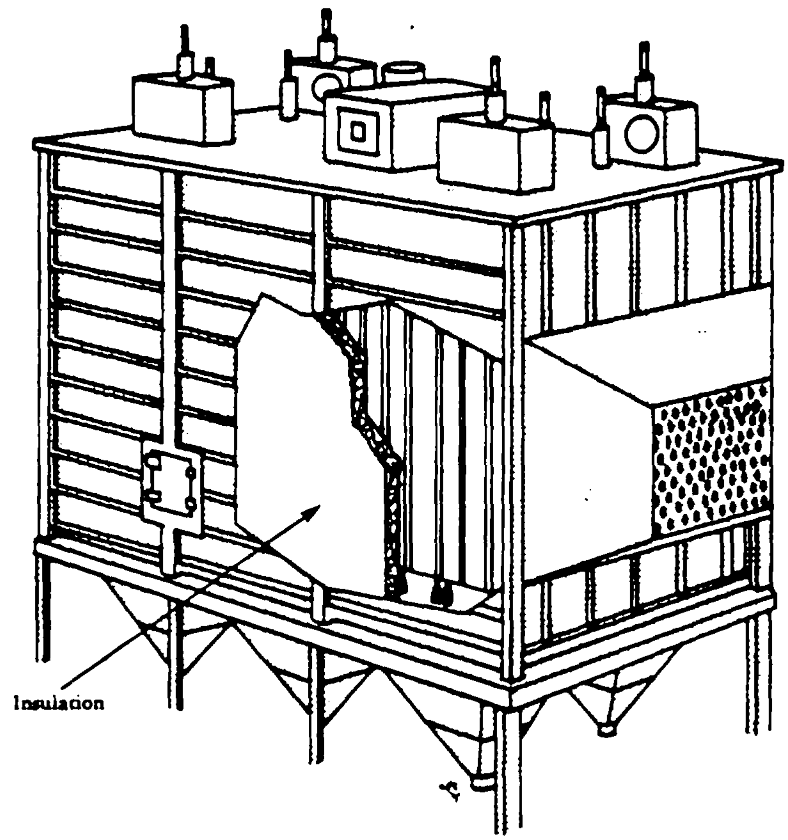

Figure 4-10. Shell.

Rappers

Dust that has accumulated on collection and discharge electrodes is removed by *rapping*. Dust deposits are generally dislodged by mechanical impulses or vibrations imparted to the electrodes. A rapping system is designed so that rapping intensity and frequency can be adjusted for varying operational conditions. Once the operating conditions are set, the system must be capable of maintaining uniform rapping for a long time.

Hammer

Collection plates are rapped by a number of methods. One rapper system uses hammers mounted on a rotating shaft as shown in Figure 4-11. As the shaft rotates, the hammers drop (by gravity) and strike anvils that are attached to the collecting plates. Rappers can be mounted on the top or on the side of collection plates.

Rapping intensity is controlled by the weight of the hammers and the length of the hammer mounting arm. The frequency of rapping can be changed by adjusting the speed of the rotating shafts. Thus, rapping intensity and frequency can be adjusted for the varying dust concentration of the flue gas.

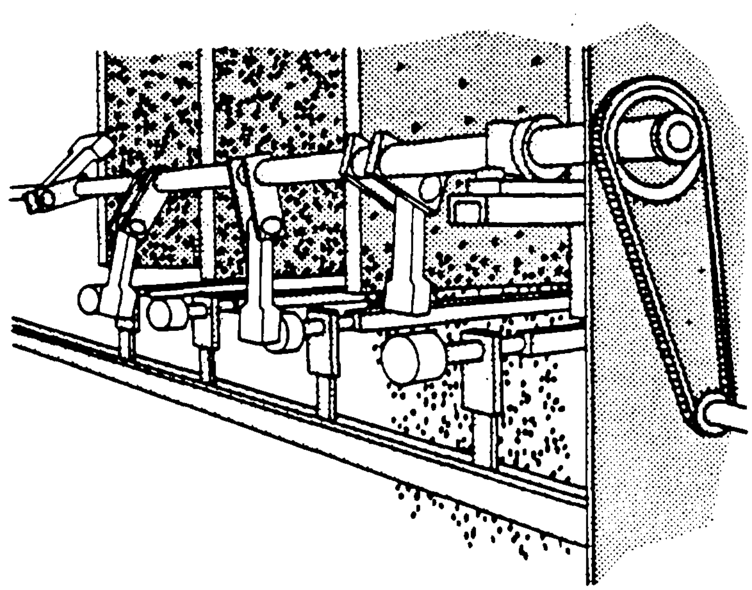

Figure 4-11. Typical hammer/anvil rappers for collection plates.

Magnetic Impulse

Another rapping system used for many U.S. designs consists of *magnetic impulse rappers* to remove accumulated dust layers from collection plates. A magnetic impulse rapper has a steel plunger that is raised by a current pulse in a coil. The raised plunger then drops back, due to gravity, striking a rod connected to a number of plates within the precipitator as shown in Figure 4-12. Rapper frequency and intensity are easily regulated by an electrical control system. The frequency may be one rap every few minutes to one rap an hour with an intensity of 10 to 24 g's (Katz, 1979). Magnetic impulse rappers usually operate more frequently but with less intensity than do rotating hammer/anvil rappers.

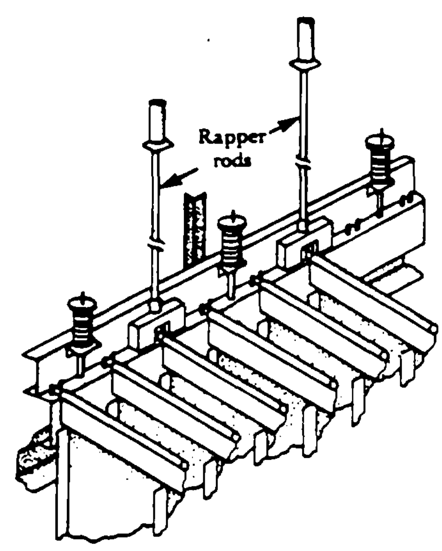

Figure 4-12. Typical magnetic impulse rappers for collection plates.

Electric Vibrator

The discharge or corona electrodes must also be rapped to prevent excessive dust deposit buildup that will interfere with corona generation. This is usually accomplished by the use of *air* or *electric vibrators* that gently vibrate the discharge wires. Vibrators are usually mounted externally on precipitator roofs and are connected by rods to the high tension frames that support the corona electrodes (Figure 4-13). An insulator, located above the rod, electrically insulates the rapper while mechanically transmitting the rapping force.

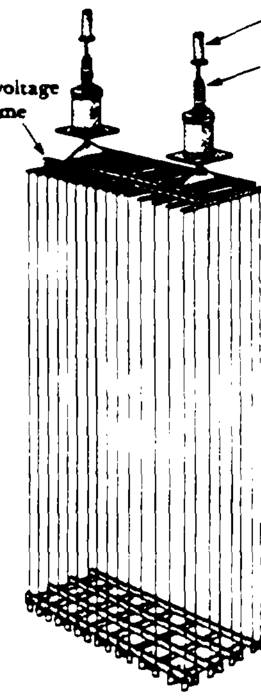

Figure 4-13. Typical vibrator rappers used for discharge electrodes.

Tumbling Hammers for Rigid Frame Discharge Electrodes

Rigid frame discharge electrodes are rapped by tumbling hammers. The tumbling hammers operate similarly to the hammers used to remove dust from collection electrodes. The hammers are arranged on a horizontal shaft. As the shaft rotates, the hammers hit an impact beam which transfers the shock, or vibration, to the center tubes on the discharge system, causing dust to be removed (Figure 4-14).

Transformer-Rectifier Sets

High voltage equipment controls the strength of the electric field generated between the discharge and collection electrodes. This is accomplished by using transformer-rectifier (T-R) sets. The transformer steps up the voltage from 400 volts to approximately 20,000 to 70,000 volts. This high voltage helps to increase particle movement to the collection plates. The rectifier converts alternating current to direct current. Direct (or undirectional current) is required for electrical precipitation. Most modern precipitators use solid-state silicon rectifiers and oil or askerel-filled high voltage transformers.

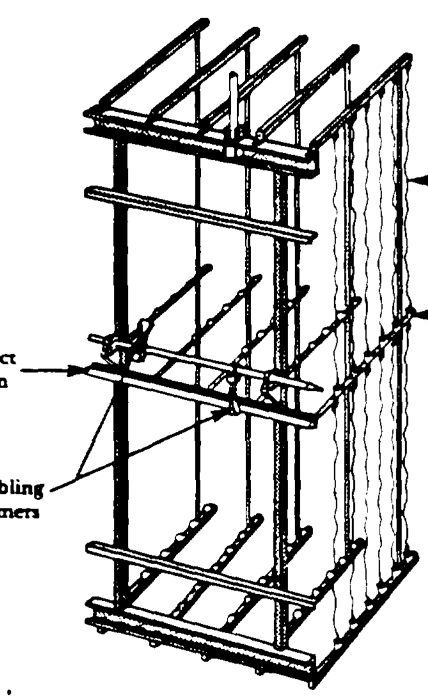

Figure 4-14. Tumbling hammers for rigid frame discharge electrodes.

Review Exercise

1. The discharge electrodes in most U.S. precipitator designs are a. thin plates usually between 20 and 50 feet high. b. thin round wires varying from 0.05 to 0.15 inch in diameter. c. rigid frames.	
2. Collection plates are usually spaced a. more than 15 inches apart. b. from 8 to 12 inches apart. c. less than 4 inches apart.	1. b. thin round wires varying from 0.05 to 0.15 inch in diameter.
3. Two rappers used for removing accumulated dust from collection electrodes are a. electric vibrator rappers. b. pneumatic rappers. c. magnetic impulse rappers. d. hammer and anvil rappers.	2. b. from 8 to 12 inches apart.
4. True or False? Occasionally, discharge electrodes must be rapped to prevent excessive dust deposits on them that interfere with corona generation.	3. c. magnetic impulse rappers. d. hammer and anvil rappers.
5. The transformer-rectifier sets are used a. to step down the voltage and convert alternating current to direct current. b. to step up the voltage to approximately 20,000 to 70,000 volts and to convert alternating current to direct current. c. to step up the voltage to approximately 70,000 volts and to convert direct current to alternating current.	4. True
6. True or False? Electrostatic precipitators cannot be used for collecting dust from cement kilns or basic oxygen steel furnaces because the flue gas temperatures are too high.	5. b. to step up the voltage to approximately 20,000 to 70,000 volts and to convert alternating current to direct current.
	6. False

ESP Operation

ESPs have been used in many industrial applications. The design of the ESP depends on various process variables such as flue gas temperature and flow rate, dust concentration, and the physical and chemical properties of the dust.

Resistivity

Particle resistivity is a condition of the particle in the flue gas that can drastically affect ESP collection efficiency. Resistivity describes the resistance of the collected dust layer (on the plates) to the flow of electric current. Particles that have high resistivity are more difficult to collect than those having normal resistivity. This is because the collected dust layer tends to break down the flow of electric current from the discharge electrode to the collection electrode. Particles that have high resistivity do not leak their charge to ground upon arrival at the collection plate. Consequently, ESP performance is reduced. High resistivity problems occur most frequently when low sulfur coal is burned in boilers. The collection efficiency of some ESPs has been reduced as much as 50% due to resistivity problems (White, 1974).

High resistivity can be reduced by adjusting the temperature and moisture content of the flue gas flowing into the ESP. Particle resistivity can be decreased by increasing the gas temperature above 260°C (500°F) or by reducing it below 150°C (300°F). Hot-side precipitators have frequently been used to combat resistivity problems, where the flue gas temperature into the ESP is greater than 260°C. However, it has been reported that the efficiency of hot-side ESPs is quite sensitive to the composition of fly ash, and since the composition of fly ash is highly variable, reliable operation can be difficult.

Increasing the moisture content of the flue gas also lowers resistivity. This can be accomplished by spraying water or injecting steam into the duct work preceding the ESP. In both temperature adjustment and moisture conditioning, the flue gas must be above the dew point to prevent corrosion problems to the precipitator.

Other conditioning agents such as sulfuric acid, sulfur trioxide, ammonia, sodium chloride, and soda ash have also been used to reduce particle resistivity (White, 1974). For coal fly ash, the resistivity can be lowered by injecting approximately 10 to 30 ppm sulfur trioxide into the flue gas ducts preceding the ESP.

Specific Collection Area

The specific collection area (SCA) is defined as the ratio of the collection surface area to the gas flow rate into the ESP. Increasing the surface area for a given flue gas flow rate will generally increase the collection efficiency of the precipitator. Typical designs use an SCA of 20 to 25 m^2 of collecting surface for every 1000 m^3/hr gas flow rate (350 to 400 ft^2 per 1000 acfm). The general range of SCA is between 11 and 45 m^2 plate surface area per 1000 m^3/hr gas flow rate (200 to 800 ft^2 per 1000 acfm).

Aspect Ratio

Large ESPs typically use plates that are 9.2 m (30 ft) high. The length of the plates varies, but generally, the longer the plates are, the better the collection efficiency will be. The aspect ratio is defined as the ratio of the total length to height of collector surface. The aspect ratio for ESPs can range from 0.5 to 2.0. For 99.5^+ percent collection efficiency, the precipitator design should have an aspect ratio of greater than 1.0. Therefore, if the plate is 9.2 m high, the length should be at least 9.2 m.

ESPs have been used in many industries to reduce particulate emissions. ESPs have been installed on over a thousand power plants throughout the U.S. to control fly ash emissions. These units have been designed in some cases to collect micron-sized particles and have collection efficiencies exceeding 99%. ESPs are generally more efficient in collecting very small particles than cyclones and scrubbers. ESPs are relatively inexpensive to operate compared to baghouses and scrubbers since the pressure drops across ESPs are low. ESPs also are very useful for filtering high-temperature flue gas, such as in a power plant or cement kiln.

Review Exercise

1. When the collected dust layer resists the flow of electric current, the condition is called a. normal resistivity. b. high resistivity.	
2. True or False? A change in particle resistivity can affect ESP performance.	1. b. high resistivity.
3. High resistivity can be reduced by a. burning low sulfur coal. b. increasing the temperature above 260°C. c. spraying water or injecting steam into the duct work that precedes the ESP. d. all the above e. b and c only	2. True
	3. e. b and c only

4. Increasing the collection surface area for a given flue gas flow rate will generally increase/decrease the collection efficiency of the precipitator.	
5. The ratio of the total length of a collection surface to its height is called the a. specific collection area. b. corona discharge ratio. c. acfm. d. aspect ratio. e. none of the above	4. increase
6. The ________ for ESPs can range from 0.5 to 2.0. Collection efficiency is generally better when this is greater than ________.	5. d. aspect ratio.
	6. aspect ratio, 1.0

References

Anderson, E. 1924. Report, Western Precipitator Co., Los Angeles, CA, 1919. *Trans. Amer. Inst. Chem. Eng.* 16:69.

Bethea, R. M. 1978. *Air Pollution Control Technology—an Engineering Analysis Point of View*. New York: Van Nostrand Reinhold Company.

Cheremisinoff, P. N. and Young, R. A., eds. 1977. *Air Pollution Control and Design Handbook Part 1*. New York: Marcel Dekker, Inc.

Cross, F. L. and Hesketh, H. E., eds. 1975. *Handbook for the Operation and Maintenance of Air Pollution Control Equipment*. Westport, Conn.: Technomic Publishing Co., Inc.

Deutsch, W. 1922. *Ann. Phys. (Leipzig)* 68:335.

Environmental Protection Agency (EPA). 1981. *APTI Course 413 Control of Particulate Emissions—Student Manual*. EPA 450/2-80-066.

Environmental Protection Agency (EPA). 1979. *Particulate Control by Fabric Filtration on Coal Fired Industrial Boilers*. EPA 625/2-79-021.

Environmental Protection Agency (EPA). 1976. *Capital and Operating Costs of Selected Air Pollution Control Systems*. EPA 450/3-76-014.

Environmental Protection Agency (EPA). 1973. *Air Pollution Engineering Manual*. 2nd ed. AP-40.

Hesketh, H. E. 1979. *Air Pollution Control*. Ann Arbor: Ann Arbor Science Publishers, Inc.

Katz, J. 1979. *The Art of Electrostatic Precipitators*. Munhall, Pennsylvania: Precipitator Technology, Inc.

Rose, H. E. and Wood, A. J. 1956. *An Introduction to Electrostatic Precipitation in Theory and Practice*. London: Constable and Company.